A look at different systems and their architectures

- **HZRS** aims at automatic recognition of handwritten zip code recognition.

- The process involves
  - hypothesizing the location of the ZIP code on the envelope
  - segmenting and recognizing ZIP code digits,
  - locating and recognizing City and State names,
  - looking-up the results in a dictionary (ZIP vs. City/State)

- Different image recognition/pattern recognition algorithms.
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What styles are involved in e-mail communication?
What styles are involved in e-mail communication?

- Client-server

and many more...
Software architecture: Architecture Description Languages

Alexander Serebrenik
This week sources

Welcome to the ISO/IEC/IEEE 42010 Website


Software Architecture
Foundations, Theory, and Practice

Richard N. Taylor • Nenad Medvidovic • Eric M. Dashofy
Architecture description language

- Architecture description elements should be somehow expressed

- An **architecture description language (ADL)** is any form of expression for use in architecture descriptions.
  - provides **one or more model kinds** to frame **concerns** of its **stakeholders**
Architecture description language

• Architecture description elements should be somehow expressed

• An architecture description language (ADL) is any form of expression for use in architecture descriptions.
  • provides one or more model kinds to frame concerns of its stakeholders:
    – narrowly focused (a single model kind)
    – widely focused (several model kinds; optionally organized in viewpoints)
  • often supported by automated tools to aid the creation, use and analysis of its models.
Examples of ADLs?

• An architecture description language (ADL) is any form of expression for use in architecture descriptions.

• You already know at least three architecture description languages

• Who can name them?
Examples of ADLs?

• An architecture description language (ADL) is any form of expression for use in architecture descriptions.

• You already know at least three architecture description languages

• Who can name them?
  • UML
  • Natural language
  • Notation we’ve used do describe architectural styles
Goal of this lecture

- Review and compare different ADLs
- We need comparison criteria!
  - Similarly to the analysis we have done for architectural styles
Evaluating ADLs: Criteria and Examples

• **Scope and purpose**
  • What does the technique help you model? What does it *not* help you model?
    − NL: capture design decisions in prose form
    − UML: design decisions in 13 diagram types

• **Basic elements**
  • What are the basic elements (the ‘atoms’) that are modeled? How are they modeled?
    − NL: any concepts required
    − UML: classes, associations, activities, nodes, use cases…
Evaluating ADLs: Criteria and Examples

- **Static and dynamic aspects**
  - What static (~structural) and dynamic (~behavioral) aspects of an architecture does the approach help you model?
    - NL: any aspect can be modelled
    - UML: some static diagrams (class, package), some dynamic (state, activity)

- **Dynamic modeling**
  - To what extent does the approach support models that change as the system executes?
    - NL: done manually, tool support: text editor
    - UML: depends on the environment but usually limited
• **Non-functional aspects**
  • To what extent does the approach support (explicit) modeling of non-functional aspects of architecture?
    - NL: expressive vocabulary available (but no way to verify)
    - UML: almost no direct support; natural-language annotations
      - exception: time behavior – UML timing diagrams.
Evaluating ADLs: Criteria and Examples

- **Ambiguity**
  - How does the approach help you to avoid (or embrace) ambiguity?

- NL is inherently ambiguous
  - “John saw the man on the mountain with a telescope”.
  - Who has the telescope? John, the man on the mountain, or the mountain?
Ambiguity

- How does the approach help you to avoid (or embrace) ambiguity?

- NL is inherently ambiguous

Possible solution

The (name) interface on (name) component takes (list-of-elements) as input and produces (list-of-elements) as output (synchronously | asynchronously).

- Can make data easier to read and interpret,
- However, such information is generally better represented in a more compact format…
Evaluating ADLs: Criteria and Examples

- **Ambiguity**
  - How does the approach help you to avoid (or embrace) ambiguity?

- **UML**
  - **Dependency**: the source uses the target in order to realize its functionality (but does not include an instance of it)
    - does A call B? use B? create B?...
    - solution: “profiles”

```plaintext
A <<call>> B
        ^        ^
        |        |
     <<use>>  <<create>>
```

/ SET / W&I
Evaluating ADLs: Ambiguity Summary

• **Ambiguity**
  • How does the approach help you to avoid (or embrace) ambiguity?
    - NL: tends to be ambiguous; statement templates and dictionaries help
    - UML: many symbols are interpreted differently depending on context; profiles reduce ambiguity
Evaluating Modeling Approaches (cont’d)

• **Accuracy**
  • How does the approach help you to assess the correctness of models?
    – NL: manual
    – UML: syntactic well-formedness checks, manual

• **Precision**
  • At what level of detail can various aspects of the architecture be modeled?
    – NL/UML: at any level
Evaluating Modeling Approaches

• **Viewpoints**
  • Which viewpoints are supported by the approach?
    – NL: any viewpoint (but no specific support for any particular viewpoint)
    – UML: each diagram type can be associated with at least one viewpoint
Evaluating Modeling Approaches

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• **Viewpoint Consistency**
  - How does the approach help you assess or maintain consistency among different viewpoints?
    - NL: manual
    - UML: little in the languages itself; research prototypes

**Validation**

- **Recall**: Interaction diagrams should be consistent with the corresponding class diagrams and use case diagrams
- **Rule**: Objects in [sd] should be instances of classes in [cd]
- **Rule**: Name of the message [sd] should match an operation in the receiver’s class [cd]
Surveying Modeling Approaches

- **Generic approaches**
  - Natural language
  - UML, the Unified Modeling Language
  - PowerPoint-style modeling

- **Early architecture description languages**
  - Darwin
  - Rapide
  - Wright

- **Domain- and style-specific languages**
  - Koala
  - Weaves
  - AADL

- **Extensible architecture description languages**
  - Acme
  - ADML
  - xADL

and there are more!
Informal Graphical Model Example

User Interface Component

Display simulator status, get new burn rate, invoke calculation

Calculation Component

Take burn-rate, calculate new height, velocity, fuel, simulator time, check for termination

Data Store Component

Store height, velocity, fuel, simulator time.
Informal Graphical Modeling

• General diagrams produced in tools like PowerPoint

• Advantages
  • Can be aesthetically pleasing
  • Size limitations (e.g., one slide, one page) generally constrain complexity of diagrams
  • Extremely flexible due to large symbolic vocabulary

• Disadvantages
  • Ambiguous, non-rigorous, non-formal
    – But often treated otherwise
  • Cannot be effectively processed or analyzed by machines/software
Related Alternatives

• Some diagram editors (e.g., Microsoft Visio) can be extended with semantics through scripts and other additional programming
  • Generally ends up somewhere in between a custom notation-specific editor and a generic diagram editor
  • Limited by extensibility of the tool

• PowerPoint Design Editor (Goldman, Balzer) was an interesting project that attempted to integrate semantics into PowerPoint
Informal Graphical Evaluation

- **Scope and purpose**
  - Arbitrary symbols + text diagrams

- **Basic elements**
  - Geometric shapes, splines, clip-art, text segments

- **Static & Dynamic Aspects**
  - Any aspect can be modeled, but no semantics behind models

- **Dynamic Models**
  - Rare, although APIs to manipulate graphics exist

- **Non-Functional Aspects**
  - With natural language annotations

- **Ambiguity**
  - Symbolic vocabulary/dictionaries

- **Accuracy**
  - Manual reviews and inspection

- **Precision**
  - Up to modeler; generally canvas is limited in size (e.g., one ‘slide’)

- **Viewpoints**
  - Any viewpoint

- **Viewpoint consistency**
  - Manual reviews and inspection
Darwin: an early ADL [Magee, Kramer 1991]

- General purpose architecture description language
  - graphical and textual visualizations
  - focused on structural modeling of systems

- Advantages
  - Simple mechanism for modeling structural dependencies
  - Repeated elements through programmatic constructs
  - Can be modeled in pi-calculus for formal analysis
  - Can specify hierarchical (i.e., composite) structures

- Disadvantages
  - Limited usefulness beyond simple structural modeling
  - No notion of explicit connectors
    - Although components can act as connectors
component DataStore{
    provide landerValues;
}

cOMPONENT Calculation{
    require landerValues;
    provide calculationService;
}

cOMPONENT UserInterface{
    require calculationService;
    require landerValues;
}

cOMPONENT LunarLander{
    inst
        U: UserInterface;
        C: Calculation;
        D: DataStore;
    bind
        C.landerValues -- D.landerValues;
        U.landerValues -- D.landerValues;
        U.calculationService -- C.calculationService;
}
component WebServer{
    provide httpService;
}

component WebClient{
    require httpService;
}

component WebApplication(int numClients){
    inst S: WebServer;
    array C[numClients]: WebClient;
    forall k:0..numClients-1{
        inst C[k] @ k;
        bind C[k].httpService -- S.httpService;
    }
}
Darwin Evaluation

- Scope and purpose
  - Modeling software structure
- Basic elements
  - Components, interfaces, configurations, hierarchy
- Static & Dynamic Aspects
  - Mostly static structure; some additional support for dynamic aspects through lazy and dynamic instantiation/binding
- Dynamic Models
  - N/A
- Non-Functional Aspects
  - N/A

- Ambiguity
  - Rigorous, but structural elements can be interpreted in many ways
- Accuracy
  - Pi-calculus analysis
- Precision
  - Modelers choose appropriate level of detail through hierarchy
- Viewpoints
  - Structural viewpoints
- Viewpoint consistency
  - N/A
• Specifies structure and formal behavioral specifications for interfaces between components and connectors

• Advantages
  • Structural specification similar to Darwin
  • Formal interface specifications can be translated automatically into CSP and analyzed with tools
    - Communicating sequential processes
    - Can detect subtle problems e.g., deadlock

• Disadvantages
  • High learning curve
  • No direct mapping to implemented systems
  • Addresses a small number of system properties relative to cost of use
Wright Example

<table>
<thead>
<tr>
<th>Component DataStore</th>
<th>Port getValues (behavior specification)</th>
<th>Port storeValues (behavior specification)</th>
<th>Computation (behavior specification)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component Calculation</td>
<td>Port getValues (behavior specification)</td>
<td>Port storeValues (behavior specification)</td>
<td>Port calculate (behavior specification)</td>
</tr>
<tr>
<td>Component UserInterface</td>
<td>Port getValues (behavior specification)</td>
<td>Port calculate (behavior specification)</td>
<td>Computation (behavior specification)</td>
</tr>
</tbody>
</table>

**Connector Call**

- **Role Caller** = \( \text{Call} \rightarrow \text{return} \rightarrow \text{Caller}[] \)
- **Role Callee** = \( \text{Call} \rightarrow \text{return} \rightarrow \text{Callee}[] \)

\[
\text{Caller.call} \rightarrow \text{Callee.call} \rightarrow \text{Glue}
\]

\[
[] \text{Callee.return} \rightarrow \text{Caller.return} \rightarrow \text{Glue}
\]
Component DataStore
   Port getValues (behavior specification)
   Port storeValues (behavior specification)
   Computation (behavior specification)

Component Calculation
   Port getValues (behavior specification)
   Port storeValues (behavior specification)
   Port calculate (behavior specification)
   Computation (behavior specification)

Component UserInterface
   Port getValues (behavior specification)
   Port calculate (behavior specification)
   Computation (behavior specification)

Connector Call
   Role Caller = \text{caller} \rightarrow \text{return} \rightarrow \text{Caller}[	ext{Glue}]
   Role Callee = \text{call} \rightarrow \text{return} \rightarrow \text{Callee}
   \text{Call}\text{.call} \rightarrow \text{Callee\text{.call}} \rightarrow \text{Glue}
   \text{Glue} = [[\text{Callee\text{return}}} \rightarrow \text{Caller\text{return}}} \rightarrow \text{Glue}]

Configuration LunarLander
   Instances
      DS : DataStore
      C : Calculation
      UI : UserInterface
      CtoUIgetValues, CtoUIstoreValues, UItoC, UItoDS : Call

   Attachments
      C.getValues as CtoUIgetValues.Caller
      DS.getValues as CtoUIgetValues.Callee
      C.storeValues as CtoUIstoreValues.Caller
      DS.storeValues as CtoUIstoreValues.Callee
      UI.calculate as UItoC.Caller
      C.calculate as UItoC.Callee
      UI.getValues as UItoDS.Caller
      DS.getValues as UItoDS.Callee

End LunarLander.
Wright Evaluation

- **Scope and purpose**
  - Structures, behaviors, and styles of systems composed of components & connectors

- **Basic elements**
  - Components, connectors, interfaces, attachments, styles

- **Style**
  - Supported through predicates over instance models

- **Static & Dynamic Aspects**
  - Static structural models annotated with behavioral specifications

- **Dynamic Models**
  - N/A

- **Non-Functional Aspects**
  - N/A

- **Ambiguity**
  - Well-defined semantics limit ambiguity

- **Accuracy**
  - Wright models can be translated into CSP for automated analysis

- **Precision**
  - Detailed behavioral modeling possible

- **Viewpoints**
  - Single structural/behavioral viewpoint plus styles

- **Viewpoint consistency**
  - Style checking can be done automatically
Domain- and Style-Specific ADLs

• Notations we have surveyed thus far have been \textit{generically applicable} to many types of software systems.

• If you restrict the \texttt{target domain}, you can provide more advanced features and/or reduce complexity.
  • Do you recall Domain-Specific Software Architectures?

• Example of a domain-specific ADL: Koala [2000]
  • inspired by Darwin
  • product lines of embedded consumer-electronics devices
Koala Example

interface IDataStore{
    void setAltitude(int altitudeInMeters);
    int getAltitude();
    void setBurnRate(int newBurnRate);
    int getBurnRate();
    ...
}

Koala Evaluation

- **Scope and purpose**
  - Structures and interfaces of product lines of component-based systems

- **Basic elements**
  - Components, interfaces, elements for variation points: switches, diversity interfaces, etc.

- **Style**
  - Product lines might be seen as very narrow styles

- **Static & Dynamic Aspects**
  - Static structure only

- **Dynamic Models**
  - N/A

- **Non-Functional Aspects**
  - N/A

- **Ambiguity**
  - Close mappings to implementation limit ambiguity

- **Accuracy**
  - Close mappings to implementations should reveal problems

- **Precision**
  - Structural decisions are fully enumerated but other aspects left out

- **Viewpoints**
  - Structural viewpoint with explicit points of variation

- **Viewpoint consistency**
  - N/A
Extensible ADLs

• **Trade-off**
  - The expressiveness of general-purpose ADLs and
  - The optimization and customization of more specialized ADLs

• **Best of both worlds?**
  • **Use multiple notations in tandem**
    - (Difficult to keep consistent, often means excessive redundancy)
  • **Overload an existing notation or ADL (e.g., UML profiles)**
    - Increases confusion, doesn’t work well if the custom features
don’t map naturally onto existing features
  • **Add additional features we want to an existing ADL**
    - But existing ADLs provide little or no guidance for this
  • **Extensible ADLs attempt to provide such guidance**
xADL

• Modular XML-based ADL intended to maximize extensibility both in notation and tools

• **Advantages**
  • Growing set of generically useful modules available already
  • Tool support in ArchStudio environment
  • Users can add their own modules via well-defined extensibility mechanisms

• **Disadvantages**
  • Extensibility mechanisms can be complex and increase learning curve
  • Heavy reliance on tools
<types:component xsi:type="types:Component" types:id="myComp">
  <types:description xsi:type="instance:Description">
    MyComponent
  </types:description>
  <types:interface xsi:type="types:Interface" types:id="iface1">
    <types:description xsi:type="instance:Description">
      Interface1
    </types:description>
    <types:direction xsi:type="instance:Direction">
      inout
    </types:direction>
  </types:interface>
</types:component>
xADL Example

```xml
<types:component xsi:type="types:Component"
   types:id="myComp">
  <types:description xsi:type="instance:Description">
    MyComponent
  </types:description>
  <types:interface xsi:type="types:Interface"
    types:id="ifacel">
    <types:description xsi:type="instance:Description">
      Interface1
    </types:description>
    <types:direction xsi:type="instance:Direction">
      inout
    </types:direction>
  </types:interface>
</types:component>
```

```c
component{
  id = "myComp";
  description = "MyComponent";
  interface{
    id = "ifacel";
    description = "Interface1";
    direction = "inout";
  }
}
```
xADL Example

```xml
<types:component xsi:type="types:Component" types:id="myComp">
  <types:description xsi:type="instance:Description">
    MyComponent
  </types:description>
  <types:interface xsi:type="types:Interface" types:id="iface1">
    <types:description xsi:type="instance:Description">
      Interface1
    </types:description>
    <types:direction xsi:type="instance:Direction">
      inout
    </types:direction>
  </types:interface>
</types:component>
```

ArchStudio Environment

[Image of a software architecture diagram showing TV Tuner Component, P-in-P Tuner Component, TV Connector, and Infrared Receiver Component]
Scope and purpose
- Modeling various architectural concerns with explicit focus on extensibility

Basic elements
- Components, connectors, interfaces, links, options, variants, versions, ..., plus extensions

Style
- Limited, through type system

Static & Dynamic Aspects
- Mostly static views with behavior and dynamic aspects provided through extensions

Dynamic Models
- Models can be manipulated programmatically

Non-Functional Aspects
- Through extensions

Ambiguity
- Base schemas are permissive; extensions add rigor or formality if needed

Accuracy
- Correctness checkers included in ArchStudio and users can add additional tools through well-defined mechanisms

Precision
- Base schemas are abstract, precision added in extensions

Viewpoints
- Several viewpoints provided natively, new viewpoints through extensions

Viewpoint consistency
- Checkable through external tools and additional consistency rules
Software architecture: Architecture Evolution (a brief primer)

Alexander Serebrenik
How do architectures change with time?

Recall...

• **Architectural drift** is introduction of principal design decisions into a system’s descriptive architecture that
  - are not included in, encompassed by, or implied by the prescriptive architecture
  - but which **do not violate** any of the prescriptive architecture’s design decisions

• **Architectural erosion** is the introduction of architectural design decisions into a system’s descriptive architecture that **violate** its prescriptive architecture

But what happens **in practice**?
Avionics software [Anderson, Felici 2000]

- F1 concerns system architecture and is stable.
- Conjecture: system architecture is stable
  - No requirements being added
Architecture grows but the growth is limited

Number of internal dependencies in Eclipse: added, kept, kept from r1, deleted.

- Wermelinger, Yu, Lozano observed **linear growth** for architecture
- Lehman predicts linear growth of the system **size** [conservation of familiarity]
- Godfrey, Tu observe **superlinear** growth of system size in Linux
ADLs and evolution

• Current ADLs target
  • correctness: e.g., Wright [Allen 1997]
    – Recall:
      – based on Communicating Sequential Processes
      – defines consistency properties for model checking
  • system config. and code generation, e.g.,
    – Fractal [Bruneton, Coupaye, Leclercq, Quema, Stefani 2004]
      – components: **primitive** (code) and **composite** (group)
      – code generation
    – ArchJava [Aldrich, Chambers, Notkin 2002]
      – extension of Java
        – components, ports, connections
        – enforces communication integrity
Major problems with current ADLs

• No support for evolution during the execution
  • Architecture can change during the execution:
    − client connects to a different server
    − Check Müller, Villegas on Runtime evolution in
  • Snapshots easily become obsolete

• No support for evolution due to change in requirements
  • Wright
    − model checking: no incremental approach
    − minor modification $\Rightarrow$ everything should be rechecked
  • ArchJava
    − no real separation of architecture/implementation
    − overtly complex code
First attempts at solutions: Extended Wright

- Event-driven reconfiguration
  - Component description should be adapted to describe when/which reconfigurations are permitted
  - Incomplete separation of the reconfiguration policies
- Can be used to model evolution, but
  - Finite number of models
Architecture description language

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- An **architecture description language (ADL)** is any form of expression for use in architecture descriptions.
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